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OPTOELECTRONIC INTEGRATION

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TABLE OF CONTENTS

I. SUMMARY

In the past three year period, we have tackled several related projects towards the integration optical and electronic devices. We have studied different material combinations and novel device structures. Our significant accomplishments can be grouped into seven categories. These deal with the issues related to the investigation of electronic devices such as GaAs HBTs on InP substrates, quantum well optical modulators, resonant cavity-enhanced photodetectors, wavelength selective optoelectronic switching, computer simulation of optoelectronic devices, simulation of electronic states in quantum wells and superlattices under electrical field, and the efforts in growing high quality heterostructures using new material combinations.

In what follows, we address the progress in each one of the four categories mentioned above. Following a brief introduction, abstracts of publications resulting from research carried out under the ONR sponsorship are enclosed for more details. We also enclose a complete list of our publications and presentations.

II. PROGRESS MADE

II. A. AlGaAs/GaAs Heterojunction Bipolar Transistors on InP:

We have investigated the electrical properties of AlGaAs/GaAs single heterojunction bipolar transistors (HBT) grown on InP substrates by molecular beam epitaxy (MBE). Layer growth, device fabrication and measurements are carried out in our laboratory. To avoid degrading of the electrical performance of the HBTs due to dislocations resulting from the lattice mismatch between the InP substrate and the GaAs device layers, a strained layer superlattice was incorporated into the buffer. This superlattice contains eight periods of GaAs/InGaAs layers in which the In mole fraction was chosen to lattice constant of the InP substrate. The strain introduced by the alternating layers of these different materials stops the propagation of the dislocations into the active device layers, effectively improving the electrical performance.

Measured small-signal common emitter current gains were comparable to that for similar HBTs grown on GaAs substrates. The small dependence of the current gain on the current density results from the good (ideality factor of 1.3) emitter base characteristics. We have observed no degradation in the electrical performance at current densities as high as $1\text{x } 10^4$ A/cm2 demonstrating the excellent stability of the material system.

II. B. GaAs Asymmetric Coupled Quantum Well Modulators:

We have studied the electroabsorption characteristics of the GaAs asymmetric coupled quantum wells (ACQW) towards the high contrast ratio optical modulators. The coupled quantum well configuration allows the electron states to be confined in one of the quantum wells. A small electrical bias can transfer the confinement from one to the other quantum well resulting in large changes in the absorption characteristics. The absorption characteristics were investigated at room temperature and also at 4K at which the peaks corresponding to different transitions can be identified. Rapid quenching and enhancement of excitonic absorption peaks is achieved at low bias in the order of 10KV/cm.

The ideas developed through the absorption studies of GaAs ACQW were applied to the formation of reflection modulators on Si substrates. Growth of GaAs optical devices on Si has been a very attractive combination since it allows the integration of optical devices with Si electronic circuits. We have investigated the problems associated with the GaAs on Si growth over the years and accomplished excellent electrical and optical performances. The growth aspects of the ACQW modulator study also benefited from our past experience. On these devices, we obtained modulation ratios up to 4:1 for an external voltage bias of 9V.

II. C. Resonant Cavity-Enhanced Photodetectors:

The photosensitivity characteristics of resonant cavity enhanced (RCE) photodetectors has been investigated. The photodetectors were formed by integrating the active absorption region into a resonant cavity composed of top and bottom mirrors. A general expression of the quantum efficiency for RCE photodetectors was derived taking the external layer losses into account for the first time. We have also investigated the effect of the standing wave distribution inside the cavity on the quantum efficiency and accurately formulated the photosensitivity. Using our formulation, various detection properties of RCE-scheme were discussed and design parameters were studied. The conclusion we have derived were applied to experimental devices.

Gain and spectral response of heterojunction phototransistors (HPT) having a thin (0.1 µm) InGaAs strained absorbing layer in the collector have been investigated. Low dark current, and large optical gain (500) were observed. A resonant cavity composed of an AlAs/GaAs buried mirror and the native GaAs surface was used to enhance the otherwise small quantum efficiency at InGaAs absorption wavelengths resulting in a RCE-HPT. For a 0.1 µm absorbing layer an improvement of almost 7 times was demonstrated.

Under the resonance condition, the enhanced amplitude of the internal optical fields results in drastic increases in absorption and thus the quantum efficiency. Since off-resonance wavelengths are rejected from the cavity, RCE detection provides wavelength selectivity. Therefore, an array of RCE-HPTs tuned at different wavelengths can be used as a wavelength demultiplexing receiver. Using this idea a monolithic three wavelength demultiplexing receiver was fabricated. The demultiplexing ability of RCE detection predicted theoretically was therefore confirmed. A crosstalk attenuation of 12 dB and 15 dB (6:1) for three-way and dual demultiplexing was obtained, respectively. A crosstalk attenuation of 24 and 40 dB for ten- and four-channel demultiplexing is predicted with the proper design of cavity parameters.

Using a low loss, high-quality factor Q cavity, reasonably high photosensitivities can be achieved for very thin active layers. Consequently, as a results of relaxing the transit time limit on the high speed performance, the bandwidth-efficiency product can be enhanced by a factor of 4. Besides the analytical study of the high speed performance, we have also accomplished accurate prediction of the time dependent pulse response of RCE detectors through computer simulations.

The resonant cavity effect can also be used in obtaining nearly unity quantum efficiencies at selected wavelengths, without requiring thick absorption layers or anti-reflection coating. We predicted quantum efficiencies more than 99% to be accessible through the RCE detection scheme.

We have also studied the incident angle dependence of the RCE-detection. This dependence increases with the increasing finesse of the cavity. For small changes in the incident angle (less than 5 degrees) no appreciable change in the sensitivity is expected.

In brief, the detection mechanism of RCE-photodetectors was studied theoretically and the prediction were confirmed by experimental results. The formulation presents a useful tool for device design with optimized cavity parameters. Using the formulation and intuition we have developed, we have investigated a novel combination of group IV semiconductors (Ge,Si) with various compound semiconductors towards potential fast, high sensitivity detectors at wavelengths ranging from visible to 1.55 μm. Optical, electrical and material properties are carefully considered and two RCE-detector structures were proposed: Ge detectors with GaAs/AlAs cavities for optical communication wavelengths, and Si detectors with GaP/AlP cavities for visible spectrum. We have calculated the photosensitivity and spectral response of these devices for different cavity parameters.

II. D. Wavelength Selective Optoelectronic Switches

Operation principle and bistable characteristics for N-p-n-p structures where a heterojunction bipolar transistor (or a phototransistor) drives a light emitting device are studied. The bistable operation of N-p-n-p structures is combined with the wavelength selectivity of the RCE-scheme towards the realization of wavelength selective optoelectronic switches. The layers for these devices are grown by molecular beam epitaxy (MBE) and fabricated using conventional lithography. Electrical and optical characterizations are carried out within our capabilities.

We have studied the bistable operation of N-p-n-p structures. Such an optoelectronic switching device consisting of an AlGaAs/GaAs HPT vertically integrated with an InGaAs Quantum Well LED was realized. Novel two wavelength ON/OFF switching in N-p-n-p structures was demonstrated. The resulting Wavelength Discriminating Optical Switch (WDOS) is capable of performing AND and OR logic functions of two distinct wavelengths and generate an output at a third wavelength in addition to optical set/reset memory capability. Combining the bistable operation of N-p-n-p devices with the RCE-detection, we have demonstrated a novel WDM optical switch enabling the monolithic fabrication of devices with complementary photosensitivies. Such wavelength selective optical devices have implications for optical interconnects and future optical computers. Wavelength selectivity allows a number of wavelengths to be used simultaneously while small crosstalk is maintained between the nearby devices reducing the number of optical fibers required for data transmission.

II. E. Simulations of Optoelectronic Devices:

We nave investigated various optoelectronic devices through computer simulations. We have developed a theoretical model for the I-V characteristics of optically controlled MESFETs. The model considers the non uniform Gaussian doping for ion-implanted channels, and takes photogenerated carriers as well as the carriers resulting from doping. The gradual channel and the velocity saturation approximation are applied to the study of I-V characteristics of long-channel and short-channel MESFETs, respectively. Results for both kinds indicate that drain saturation current and transconductance can be improved by properly fixing the optical flux, and the absorption coefficient of the material.

To analyze the high speed properties of RCE-photodetectors, we developed a simulation program using a direct circuit simulator. The resuiting software is capable of accurately predicting the pulse response of photodetectors through the time dependent solution of drift-diffusion and Poisson equations. Preliminary results suggest a strong dependence of the response time on the number of carriers generated in neutral regions illustrating a clear advantage of RCE-detection, which is capable of limiting the carrier generation to the depletion region, over the conventional structures.

Our simulation results show a drastic improvement in the speed of response when the generation is limited to a thin layer within the depletion region of p-i-n photodetectors. The response speed is only limited by the capacitance of the device. Using state-of-the-art fabrication of optoelectronic devices, very small devices can be realized eliminating the capacitance limit. We predict resonant cavity-enhanced photodetectors working at 100 GBits/s or even higher bit rates.

II. F. Simultions of Electronic States in Semiconductor Quantum Wells and Superlattices under Electrical Field

The studies of electronic and optical properties of semiconductor quantum wells (QWs) and superlattices (SLs) in the presence of an external electric field have attracted increasing interests for their potential applications in opto-electronic devices. The quantum confined Stark effect (QCSE) has been widely used in modulation of absorption in optical detectors and wavelength switching and tuning in semiconductor lasers. The superior characteristic of the field-induced modulation and switching over other schemes is the high-speed modulation and switching capability.

In order to study the detail properties of optical process in QWs and SLs under an electric field, it is essential that the electronic states are fully understood. Using the transfer matrix technique, we have simulated the electronic surface states and minigap states confined to the boundary of semi-infinite superlattices.

When a SL structure is terminated by a surface boundary potential, under certain conditions, localized electronic surface states can be introduced. The existence of surface states had been a controversial problem in solid state physics, until the recent experimental confirmation of surface states in SLs. Our computer simulation can provide precise result for surface states without electric field as compared to exact calculations. In the presence of electric field, no analytical approach is attainable. Our numerical approach can simulate the eigenenergies and lifetime of the quasi-confined surface states. Ref.1

If a single QW is embedded between two semiconductor SLs, so-called minigap states confined by the SL forbidden gap, may exist. The minigap states provide an analogy to the impurity states in bulk semiconductor materials. Since the minigap states require no confining potential barriers from individual quantum wells, it is therefore possible to confine an electronic state without potential barriers. Although extensive theoretical studies have been carried out during the last few years, no convincing observation of this kind of confined states has been reported. Our simulation of the minigap states under an electric field will be especially useful in experimental observation of this kind of states by photoluminescence and photocurrent measurements.

Computer simulation using the transfer matrix technique is being carried out for the simulation of Bloch electrons in superlattices under an electric field. The purpose of this study is to provide a detail picture about Wannier-Stark localization and Franz-Keldysh effect in SLs under an electric field.

II. G. Growth of Heterostructures:

A custom made Gas Source MBE was installed to investigate phosphorus based III-V semiconductors. However the unique heterojunction properties and low interface recombination velocity of InGaP/GaAs system makes it a particularly interesting investigation. The GSMBE system features an integrated safety system which has been designed with the principle of total confinement of gas in the event of malfunction. It consists of a network of interlocks and continuous toxic gas monitoring which is coordinated with the gas cabinet control panel so as to trigger appropriate warning and emergency level conditions followed by specific shut downs.

On the initial InGaP on GaAs layers a low temperature photoluminescence linewidth of 6.7 meV and a room temperature electron mobility of 1500 cm^2/V-s were obtained at 300K which were enhanced to 3700 cm2/V-s at 77K. A 0.01 degrees FWHM from X-Ray rocking curve was also observed for the nominally matched epilayer. In addition to this, ellipsometry technique was utilized to map out the E1 value (3.23 eV for $In_{0.51}Ga_{0.49}P$) from the dielectric spectra of the material. Apart from observing a compositional dependence of E_1, the information regarding the broadening of the E_1 gap was utilized to understand the crystal quality of the material.

The epilayers which were below the critical thickness around the lattice matched composition had their E1 gap reduced due to misfit strain, and even the heavily lattice mismatched composition epilayers showed the presence of only partial relaxation as showed by the presence of a lower E_1 gap value. We also observed for the first time the presence of intrinsic interfacial strain which causes a lowering of E_1 gap at the lattice matched composition. It may be explained by the existence of monolayer of InGaAs at the InGaP/GaAs interface which may be inadvertently formed during the switching of the group V beams. The resulting tension in the InGaP gives rise to a lowering of the E_1 gap. Preliminary analysis of $[1\,\bar{1}\,0]$ TED pattern of a lattice matched InGaP/GaAs do not show any presence of ordering along the [111] direction. This conforms to the results of GSMBE grown InGaP results from other research groups.

We have also improved our optical characterization capabilities. A set up for far field pattern and L-I curve measurements was assembled.

Towards the realization of GaAs optoelectronic devices with Ge active regions, Ge/GaAs growth by MBE was studied and methods such as low initial growth temperatures for reducing Ga outdiffusion during Ge on GaAs growth were developed. The use of a thin AlAs spacer was demonstrated to reduce the Ga diffusion drastically. We have analyzed the material properties of the MBE grown layers using secondary ion mass spectroscopy (SIMS), X-ray photoemission spectroscopy (XPS), capacitance-voltage, and temperature dependent Hall-effect measurements. The use of a thin AlAs spacer was demonstrated to reduce the Ga diffusion drastically.

III. REPRESENTATIVE

ABSTRACTS

INFRARED PHOTOLUMINESCENCE OF InAs EPILAYERS

GROWN ON GaAs and Si SUBSTRATES

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ABSTRACT

Infrared photoluminescence measurements of InAs epilayers grown on Si and GaAs substrates reveal well defined peaks (FWHM ~ 4 meV) associated with band-to-band transitions and impurity / defect associated transitions. When compared to the epilayers grown on GaAs, the spectra of the epilayers grown on Si are shifted toward lower energy by roughly 15 meV. In addition, optical transmission measurements reveal two intrinsic absorption edges for the epilayers grown on Si. This data is interpreted in terms of biaxial strain induced between the epilayer and the substrate due to differing indices of linear thermal expansion.

AlGaAs/GaAs Single Heterojunction Bipolar Transistors Grown on InP by Molecular Beam Epitaxy

by

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ABSTRACT

AlGaAs/GaAs single heterojunction bipolar transistors grown on InP substrates by molecular beam epitaxy have been fabricated and tested. An eight period 25 Å /25 Å $In_{0.53}Ga_{0.47}As$/GaAs strained layer superlattice is incorporated in the buffer structure to reduce dislocation propagation to the active region. Small-signal common emitter current gains of about 20 and 30 at a collector current density of 2 x 10^3 A/cm ^{2} have been obtained for devices on InP as compared to about 60 and 150 for those on GaAs in structures with base thickness of 0.12 μm doped with Be to 1 x 10^{19} and 1 x 10^{18}cm^{-3}, respectively. Current densities as high as 1 x 10^4 A/cm ^{2} have been achieved in these devices with emitter area of 50 x 50- μm^2 without degradation demonstrating the excellent stability of this material. From the collector current dependence of the current gain, ideality factors of 1.3 and 1.2 for the emitter junctions have been obtained for devices on InP and GaAs, respectively.

Electroabsorption Studies on GaAs Asymmetric Coupled Quantum Wells

by

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Abstract

We report the results of electroabsorption measurement on GaAs asymmetric coupled quantum wells done at low temperature (4 K) and at room temperature (300 K). Rapid quenching and enhancement of excitonic absorption peaks is achieved at relatively low bias electric fields of the order 10 KV/cm. This is explained in terms of level anti-crossing and the subsequent switching of intrawell (spatially direct) and interwell transitions (spatially indirect) as the lowest lying conduction energy levels of the two wells are brought to resonance.

GaAs Multiple Quantum Well Reflector Modulators With 4:1 Contrast Ratios on Si.

by

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Abstract

Considerable modulation ratios are achieved for GaAs multiple quantum well reflector modulators grown on Si by inserting an AlAs/AlGaAs dielectric mirror into the device structure. Modulation ratios of up to 4:1 is attained as the external bias voltage is increased to 9 Volts and the 1C-1HH exciton absorption peak undergoes quantum confined Stark shift. Measurements also indicate that cavity effects arising from the front surface reflection and that of the imbedded dielectric mirror strongly modify the reflectivity spectra.

(a) On leave from Shin-Etsu Handotai Co. Ltd., Gunma, Japan

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Resonant Cavity Enhanced AlGaAs/GaAs Heterojunction Phototransistors with an Intermediate InGaAs Layer in the Collector

a) b)

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ABSTRACT

Gain and spectral response of a Heterojunction Phototransistors having a thin ($0.1\mu m$) InGaAs strained absorbing layer in the collector have been investigated. Low dark current $\approx$ 5pA (1×10^{-8}A/cm^2) and large optical gain, as high as 500, were observed. A resonant cavity composed of an AlAs/GaAs buried mirror structure (Reflectivity, R=0.9) and the epilayer surface (R=0.3) was used to enhance the otherwise small quantum efficiency η (at InGaAs absorption wavelength). For a 1000Å absorbing layer an improvement of η from 6.7% to 43% (6.4 fold) was demonstrated, in agreement with calculations, through the spectral analysis of the HPT's with and without resonant cavities.

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WAVELENGTH DEMULTIPLEXING HETEROJUNCTION PHOTOTRANSISTOR

Abstract: We report experimental and theoretical results on a wavelength demultiplexing receiver composed of an AlGaAs/GaAs Heterojunction Phototransistor (HPT) integrated within a resonant cavity. A high Quality Factor Q cavity was formed by using a very thin $In_{0.05}Ga_{0.95}As$ active absorption layer in the collector depletion region of the HPT. Crosstalk attenuations of 15 dB for dual and 12 dB for three wavelength demultiplexing were demonstrated. The individual HPTs had an optical gain of 500 at resonant modes. Theoretical calculations predict crosstalk attenuation levels as high as 40 dB for high reflection mirrors on both ends of the cavity.

A Safety System for Gas Source Molecular Beam Epitaxy

by

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ABSTRACT

Gas Source Molecular Beam Epitaxy (GSMBE) is one of the newest development in epitaxial growth technology wherein the group V sources such as arsine and phosphine are gaseous and in the form of hydrides while the Group III sources such as indium, aluminum, gallium are all solids. However, the gases involved are very hazardous, extremely toxic, highly inflammable and explosive at elevated temperatures. Adequate care must be taken for the safe use of these gases so that this attractive technique can be properly utilized. This paper discusses the salient safety features of one such GSMBE (installed in the Epicenter at the University of Illinois) consisting of a gas delivery system with its robust piping assembly, gas manifold and a scrubber. The system is integrated with a Multiple Point Toxic Gas Monitor (MPTGM) acting as the central alarm command system based on the concept of fail safe total safety. This alarm system is equipped with audio-visual alarms for a variety of monitored conditions and interlocks for automatic shutdown. A well designed air flow pattern has been incorporated to provide good air quality in the laboratory and in the gas storage facility. Additionally a set of good laboratory practices ensured by administrative and personal control are instituted to reduce the hazards to an acceptable risk level.

Electronic Surface State (Tamm State) Under Electric Field in Semiconductor Superlattices

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Abstract

The tunneling resonance technique is used to study the electronic surface state (Tamm state) (Phys. Rev. Lett. 64, 2555 (1990)) under an external electric field in semiconductor superlattices. The localization characteristics of the confined surface states depend on the direction and strength of the applied electric field. In the weak field regime the surface states behave delocalized due to the distortion of the periodic medium by the applied field. Our calculations can provide eigenenergy, wavefunction, and lifetime for the quasi-bound surface states, which are related directly to the optical properties of surface states under an electric field.

Electric–Field Effect on the Ministop Gap Mode in Semiconductor Superlattices

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Abstract

The electric-field effect on the ministop gap mode in coupled semiconductor superlattices is studied theoretically. Due to the perturbation of the periodicity in the superlattice by an applied field, delocalization of the confined state is observed. In the weak field regime the delocalization of the ministop gap mode is similar to the quantum confined Stark effect in single quantum wells. In the strong field regime the gap mode behaves like delocalized Stark ladders in superlattices. The confined gap state disappears, and additional states from the original superlattice miniband are introduced to form semi-bound states due to the mixing of the localized Stark ladders with the gap mode. Possible device applications are discussed.

Reduction of Outdiffusion at the Ge/GaAs (100) Interface by Low Temperature Growth

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ABSTRACT

Ga outdiffusion into Ge layers grown epitaxially by molecular beam epitaxy (MBE) was observed by secondary ion mass spectroscopy (SIMS), X-ray photoemission spectroscopy (XPS), capacitance-voltage, and temperature dependent Hall-effect measurements. Films were initially grown at low rates (0.03-0.04 nm/s) and low temperatures (150-300°C) on GaAs buffer layers on GaAs (100) substrates. The temperature and rate were then increased to 500°C and 0.1 nm/s. The amount of Ga outdiffusion was greatest for films initially grown at 300°C. No direct evidence of As outdiffusion at any temperature or Ga outdiffusion for initiation temperatures below 300°C was found. Hall-effect measurements showed higher hole concentrations and greater levels of compensation in films initiated at 300°C, consistent with outdiffusion of both Ga and As at this temperature. No degradation in the electrical characteristics of Ge-GaAs diodes was observed when the initial Ge growth temperature was reduced from 300°C to 200°C.

RESONANT CAVITY ENHANCED (RCE) PHOTODETECTORS WITH GE AND SI ACTIVE REGIONS

by

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Abstract

A novel combination of group IV semiconductors (Ge,Si) with various compound semiconductors has been considered towards potential fast, high quantum efficiency optical detectors at wavelengths ranging from the visible to 1.55 μm. Both Ge and Si are indirect band gap materials with relatively small absorption coefficients but very long carrier lifetimes. Using a resonant cavity formed by large band gap compound semiconductor mirrors around Ge and Si active layers, high photosensitivity for thin (<0.5 μm) absorbing layers can be achieved. Two different methods are discussed and compared for the accurate calculation of the photosensitivity of resonant cavity enhanced detectors. The standing wave effect and its dependence on cavity parameters are analyzed. Design rules for such resonant cavity enhanced photodetectors are presented. The spectral response of some device designs to achieve very high quantum efficiency and wavelength selectivity have been theoretically investigated.

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Gain and the Threshold of AlGaAs Single Quantum Well Laser in an Applied Electric Field

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Abstract

The optical gain and threshold current density of a GaAs-AlGaAs single quantum well laser in a static perpendicular electric field is studied theoretically. By using the tunneling resonance technique the energy eigenstates, the electron-hole overlap integral, and the lifetime of the confined carriers are obtained. The principal field effects on the laser emission are (1) reduction and broadening of the gain spectrum, (2) change in the laser wavelength, and (3) increase of the threshold current density. The homogeneous broadening of the gain spectrum due to the carrier tunneling through the barriers is considered. Based on the field-dependent shift of the peak gain position, a possible wavelength tuning mechanism for the quantum well laser is proposed. Numerical calculations show that for a 75 Å quantum well laser with the original wavelength 0.83 μm, the red-shift of the wavelength is about 5 nm in a 100 kV/cm electric field albeit with widened spectral width. A three terminal device with large range field-effect wavelength tunability is discussed.

Effect of surface carriers on the propagating waves in a cylindrical dielectric waveguide

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Abstract

Effect of a surface electron gas layer confined to a GaAs/AlGaAs quantum well on the propagating waves guided by a cylindrical dielectric waveguide is studied theoretically. By using the self-consistent energy-functional perturbation formulism, the longitudinal polarizability of the electron gas is obtained. Due to the response of the electron gas to the longitudinal electric field, it is found that the transverse TE_0 mode is not affected, while the TM_0 mode is affected by the surface carriers. The transverse TE_n and TM_n modes exist only for the lowest order (n=0) modes, which is different from a cylindrical dielectric waveguide. Calculations for the TM_0 mode show that both the phase velocity and the group velocity of the guided waves are higher than those of the dielectric waveguide without the cylindrical surface electron gas layer. Propagation constants for the hybrid HE_{11} mode are also calculated. The effects of electron gas layer on the guided waves provide new possibilities for amplitude moduation and mode siwtching in cylindrical waveguide. Our studies should also have impact in designing novel quantum well opto-electronic devices, such as, quantum wire well lasers, where the coupling of the electron gas with the propagating waves is important.

Miniband Shrinkage and Localization Properties of Electrons in Semiconductor Superlattices under Electric Field

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Abstract

A numerical technique is developed to study the electronic states in semiconductor superlattices under an external static electric field. It is found that in the weak field regime, superlattice miniband structures are retained but distorted by the field. The distortion is manifested in the form of band bending and bandwidth shrinkage. In the strong field regime, weakly localized states (Stark ladders) in the first miniband of the superlattice under consideration are found to be equidistance in spacing and become more localized as the field increases within a certain range. Calculations also indicate that the formation of Stark ladders is not a general feature pertaining to any kind of miniband structures. Our numerical simulation may provide a possible vehicle to clarify the controversy about Wannier-Stark localization of Bloch electrons in a constant electric field.

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WAVELENGTH DISCRIMINATING OPTICAL SWITCH

by

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ABSTRACT

A novel wavelength discriminating bistable optical switch (WDOS) with completely optical input/output capabilities is presented. The WDOS is a three terminal AlGaAs/GaAs N-p-n-p structure with an InGaAs/GaAs quantum well light emitting diode at the n-p junction. The WDOS can be switched to stable ON and OFF conditions by optical excitations at different wavelengths which allows the use of a single optical window. The optical switching threshold can be adjusted by the external bias. Depending on the external bias, the WDOS functions as an optical inverter, an electrically programmable optical AND/OR gate, or an all-optical read-write memory element.

WAVELENGTH DEMULTIPLEXING OPTICAL SWITCH

by

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ABSTRACT

A novel wavelength demultiplexing optical switch (WDM-OS) with completely optical input/output capabilities is demonstrated. The WDM-OS can be applied to optical logic circuits in which discrete wavelengths are utilized as an added dimension in addition to the intensity levels of the optical signals. The WDM-OS can be viewed as a resonant cavity-enhanced heterojunction phototransistor vertically integrated with a quantum well light emitting diode. The resulting device is an N-p-n-p optical switch situated in an optical cavity which serves to combine the wavelength selective spectral response of the resonant optical cavity with the bistable switching characteristics of the N-p-n-p structure.

WAVELENGTH SELECTIVE OPTICAL LOGIC AND INTERCONNECTS

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ABSTRACT

We describe a novel wavelength selective optical logic (WSOL) element which makes use of monolithically integrated wavelength selective optical input and output elements. Input optical signals are detected by photothyristors situated in an optical cavity which provides a highly selective response at a wavelength determined by the fabrication process. Output signals are generated by vertical cavity surface emitting lasers whose lasing wavelengths can also be specified during the fabrication process. We propose a vertical integration of these input and output elements which will be highly suitable for wavelength selective optical logic and wavelength selective optical interconnect applications. These devices can be fabricated to detect and emit within independently selected narrow wavelength ranges, at arbitrarily chosen positions across the wafer. The broad tunability range and the high wavelength selectivity of each WSOL device allows a large number of wavelengths to be used simultaneously while low crosstalk is maintained between nearby devices. As interconnects, the WSOL input and output elements will allow the information from many closely spaced wavelength channels to be coupled through a single optical fiber. As individual logic elements, WSOL devices are capable of completely optical logic operations at designer selected input and output wavelengths. The proposed circuitry is easily cascadable so that arbitrarily complex optical logic functions can be performed by WSOL devices in series. Several of the possible logic functions are described including OR and AND gates, an ADDER, and a FLIP-FLOP.

To ⇒ FILE!

OPTICALLY CONTROLLED CURRENT-VOLTAGE CHARACTERISTICS OF ION-IMPLANTED MESFETs

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Abstract

Optically controlled MESFETs are useful as optical devices for optical communications, and as photodetectors. In this paper, a theoretical model for the I-V characteristics of these MESFETs is presented. The model considers the nonuniform Gaussian doping for ion-implanted channels. It takes both the photogenerated carriers as well as the doping generated residual carriers into account. It is noted that the density of photogenerated carriers in the channel due to diffusion is much less than that due to drift. Treatment both under gradual channel approximation and saturation velocity approximation has been presented. The gradual channel and the velocity saturation approximations are applied to study the I-V characteristics of long-channel and short-channel MESFETs, respectively. Results for both long-channel and short-channel MESFETs indicate that drain saturation current and transconductance can be improved by properly fixing the optical flux, and the absorption coefficient of the material.

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ONE-DIMENSIONAL TRANSIENT DEVICE SIMULATION USING A DIRECT METHOD CIRCUIT SIMULATOR

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ABSTRACT

In this paper, a novel approach is presented for incorporating the transient solution of one-dimensional semiconductor drift-diffusion equations within a general circuit simulation tool. This approach allows simple representation of localized carrier transport models of simulated devices through equivalent circuit elements such as voltage controlled current sources and capacitors. As the device-level simulation is carried out by the circuit simulator using an equivalent circuit representation, this approach also lends itself to mixed-mode simulation of devices and circuits.

I. INTRODUCTION

Numerical simulation of semiconductor device operation is an increasingly important issue in the design and development of integrated circuits. Device simulation enables accurate representation of the electrical behavior of devices under various conditions as well as investigation of complex phenomena that cannot be achieved through experiments or simple analytic models. A number of device simulation tools have been developed over the years [1]-[3], and

IV. PUBLICATIONS

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